California Experience With Inside Shoulder Removals

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The problem of increasing freeway corridor capacity in a safe and cost-effective manner is becoming more difficult. One method to provide additional mixed-flow or high-occupancy vehicle (HOV) capacity is to remove shoulders and narrow lanes. In this paper, the California safety experience with inside shoulder removals that for each site generally resulted in either no significant change or a significant reduction in overall accident rates is documented. Congestion reduction appears to be the cause of the accident rate reductions. The analysis also suggests that accident severity is not affected; the only significant change in accidents is a reduction in noninjury accidents.

California has been using shoulders to increase the capacity of freeway segments since the 1970s. Some of these projects were the subject of previous reports *(1–4)*. This evaluation of freeway segments in California was performed in coordination and cooperation with the California Department of Transportation (Caltrans). Another study *(5)* was performed by the Texas State Department of Highways and Public Transportation using funds for highway planning and research from the U.S. Department of Transportation.

Freeway segments that went from full shoulders to reduced shoulders were selected for a before-and-after accident analysis. Most cases studied involved inside shoulders; some involved outside shoulders. The segments studied were located in the Los Angeles, San Francisco, and San Diego urbanized areas.

The various cases have been grouped into those for which part or all of the width of inside shoulders has been taken as a travel lane and those for which the outside shoulder has been treated. Because shoulder treatments may have an effect on upstream and downstream accidents, some of the sites immediately adjacent to the treated sites were also investigated. It was expected that, when the capacity of a segment is increased to remove a bottleneck, the site upstream may experience an accident reduction if it was experiencing congestion from the downstream bottleneck. The site downstream of the study segment was evaluated to determine if accidents were increased due to the creation of a downstream bottleneck by the increased capacity at the study site.

Computerized accident files recorded by the California Highway Patrol and maintained by Caltrans have been used as the principal source of accident data. Years 1974 through 1984 were available for analysis. Variables used to select each accident included mainlane accidents only (thus excluding ramps), direction traveled, and others required to identify the segment. The preceding data were processed using Statistical Analysis System (SAS) programs to summarize segment accidents, calculate accident rates, and compare rate differences using a two-means *t*-test. Histograms of accidents recorded each 0.1 mi along each segment also were printed to detect any abnormalities between before and after conditions.

Statistical analysis was used as a tool to aid in the analysis, which was limited by the available number of study sites and their locations. More powerful statistical testing with control cases was therefore infeasible. Nevertheless, the preponderance of evidence revealed by the statistical analysis supported the actions taken by Caltrans to improve freeway operating conditions.

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CHARACTERISTICS OF SEGMENTS STUDIED

Twelve segments where inside shoulders were removed to use as a travel lane are shown in Table 1. Seven of the segments were located in Los Angeles County, and one each was located in Orange, Marin, Alameda, Contra Costa, and San Diego Counties. Many of these segments were under 1 mi in length, and, except for I-405, all continuous subsegments were under 2 mi in length. The I-10 segments were each taken as the sum of eastbound and westbound subsegments in order to provide enough accidents for statistical analysis.

Before restriping, each segment had a full inside shoulder that was later used as a travel lane. For study purposes, shoulders 2 ft wide or narrower are considered no shoulder, those 3 to 7 ft wide are considered partial shoulder, and those 8 ft or more are considered full shoulder. Thus, there were six cases with no inside shoulders and six with partial inside shoulders after restripping. Full right shoulders are provided in all cases except I-580 where the right shoulder previously used as an auxiliary lane was turned into a permissive (peak-period) lane after restriping.

The average daily traffic (ADT) presented in Table 1 is a composite of the period covered before or after restriping. The ADT is close to or greater than 100,000 veh/day for all segments. The ADT and peak-hour traffic were obtained from the yearly *Traffic Volumes on California State Highways (6)* published by Caltrans. The number of vehicles per lane is an estimate based on peak-hour traffic, multiplied by 0.6 to account for the peak-direction traffic and divided by the number of mainlanes available along each segment. Volumes approaching or exceeding 2,000 veh/hr per lane indicate congested conditions.

TABLE 1 CHARACTERISTICS OF CALIFORNIA FREEWAYS WHERE INSIDE SHOULDERS WERE REMOVED

Seg. No.	Freeway, County Length, Direction	Beg. Mile Post	Period	Cross Section			ADT	Peak Hour Volume	Vehicles per Lane[1]
				Left Shoulder	Main Lanes	Right Shoulder			
1.	I-5, Los Angeles	36.65	Before	10'	4-12'	10'	119,500	11,300	1,700
	(1.34 mi., SB)		After	3'	5-11'	10'	133,200	12,380	1,490
2.	I-5, Los Angeles	37.80	Before	10'	4-12'	10'	119,500	11,300	1,700
	(0.69 mi., NB)		After	3'	5-11'	10'	133,200	12,380	1,490
3.	CA-22, Orange	5.82	Before	10'	3-12'	8'	123,700	10,990	2,200
	(3.25 mi., WB)		After	2'	3-11'[2]	8'	168,700	12,600	1,890
4.	CA-60, Los Angeles	15.16	Before	10'	4-12'	8'	121,300	11,820	1,770
	(0.68 mi., EB)		After	3'	5-11'	8'	112,000	11,450	1,370
5.	CA-22, Orange	16.13	Before	8'	4-12	10'	237,700	18,230	2,730
	(0.67 mi., NB)		After	3'	5-11'	10'	265,300	20,500	2,460
6.	I-405, Los Angeles	30.17	Before	10'	4-12'	10'	167,500	13,480	2,020
	(7.72 mi., NB)		After	3'	5-11'	10'	201,300	16,630	2,000
7.	US-101, Marin	14.80	Before	8'	3-12'	10'	97,800	10,740	2,150
	(0.31 mi., SB)		After	2'	4-11'	8'	106,000	11,600	1,740
8.	I-580, Alameda	42.74	Before	8'	4-12'[2]	0'	161,800	15,350	1,840
	(0.61 mi., EB)		After	3'	5-11'[3]	0'	166,900	15,830	1,580
9.	I-680, Contra Costa	17.90	Before	10'	3-12'	10'	122,000	13,450	2,690
	(0.38 mi., SB)		After	2'	4-11'	10'	133,000	14,670	2,200
10.	CA-94, San Diego	5.09	Before	8'	4-12'	8'	90,500	10,500	1,580
	(1.13 mi., EB)		After	3'	5-11'	3'	106,800	12,250	1,470

[1]Estimated (peak hour volume times 0.6 divided by number of directional lanes).

[2]Plus a full time auxillary lane.

[3]Plus a part time auxillary lane.

PROCEDURE

Overall accident rates have been calculated to compare a freeway segment before restriping with the same segment after restriping. In this calculation, accidents are first summed for each quarter or semester, as appropriate, to obtain good sample cells. The number of sample accidents are divided by the number of vehicle-miles to calculate the number of accidents per million vehicle-miles. Once this reduction is performed for the periods before and after restriping, the periods are compared using a two-means *t*-test. As designed, this test helps determine if the rate after restriping is higher or lower than before restriping and if such difference is statistically significant.

Overall accident rates include accidents classified as highway type only, and exclude those regarded as intersection or ramp. Accidents are grouped by direction of travel on the freeway. The ADT used to obtained rates is bidirectional and is therefore divided by two for analysis. Segment accidents are then plotted by direction every 0.1 mi. This is used to check any abnormalities such as exceedingly-high-accident locations and shifts along the freeway as capacity is increased.

SEGMENT COMPARISONS

Table 2 presents accident rates for each case previously given in Table 1. Mean rates are given for the periods before and after restriping. Results of the *t*-test to determine how the after accidents compare with the before accidents are also included. These results are the *t*-value, the probability that the *t*-value is greater in absolute value for the after accidents, and whether the test is statistically significant. Lane analysis would have been desirable, but excepting Segment 6, there were not enough observations for analysis.

I-5, Los Angeles

Results of the *t*-test on Segments 1 and 2 indicated that there was no significant difference in accident rates before and after restriping. The first segment, I-5 southbound, had 1.07 accidents per million vehicle-miles (acc/mvm) before restriping and 1.29 acc/mvm after restriping. Segment 1 was operating with a full inside shoulder, four mainlanes, and a full outside shoulder before restriping. After restriping, the segment had a partial inside shoulder 3 ft wide, five mainlanes, and a full outside shoulder. Table 1 presents these physical characteristics.

The number of accident samples was good for Segment 1, where accident data for 12 quarters were available for before and after comparison. Some accident samples were poor because they had five or fewer independent accident observations per quarter. Frequency bar charts of accidents recorded within every 0.1 mi along this segment reflected higher rates at mileposts 36.8 and 37.5 after restriping. However, these increases were not large enough to change the before and after difference in accident rates to a statistically significant level. No shift in accident pattern toward the downstream end could be detected after the restriping improvements.

Segment 2, I-5 northbound, had 1.18 acc/mvm before restriping and 0.78 acc/mvm after restriping. The accident rate decreased but the difference was not statistically significant. Geometric characteristics were similar to those of Segment 1; the principal treatment was the conversion of an inside shoulder into an additional travel lane, leaving a partial inside shoulder 3 ft wide.

The number of accident samples for the preceding segment was average to poor because they had to be grouped into semesters, rather than quarters, to avoid zero observation samples. Even after being grouped into semesters, some individual accident samples remained poor with five or fewer observations. Frequency bar charts are stable and minor differences between before and after may be attributed to sample variability, but with no statistical significance.

CA-22, Orange

The *t*-test for Segment 3 indicated a significant reduction in the accident rate at the 0.05 level. This segment had 0.83 acc/mvm before restriping and 0.63 acc/mvm after restriping. Restriping was done to add an auxiliary lane between on-to-off ramps without taking the right shoulder. Initially, there were a full inside shoulder, three mainlanes, and a full outside shoulder. After restriping, there were no inside shoulder, three narrower mainlanes 11 ft wide, an auxiliary lane between on-to-off ramps, and a full outside shoulder. Between off-to-on ramps, the auxiliary lane was striped off.

Samples were good in number as well as in observations per sample. The frequency bar chart reflects no major abnormality nor considerable shift, even though accidents about the midpoint at Milepost 7.8 were reduced by more than 50 percent. The latter can be the result of bottleneck relief.

CA-60, Los Angeles

The *t*-test for Segment 4 showed a nonsignificant reduction in the accident rate. This 0.68-mi segment had 0.90 acc/mvm before restriping and 0.68 ac/mvm after restriping. This segment was initially provided with a full inside shoulder, four mainlanes, and a full outside shoulder. After restriping, a partial inside shoulder 3 ft wide, five mainlanes, and the full outside shoulder remained.

Statistically, samples were poor in number and in observations per sample. The frequency bar chart reflects a reduction in accidents around milepoint 15.5, suggesting bottleneck relief as a result of the added capacity. However, observations were limited and further inferences were not possible.

US-101, Los Angeles

The result of the *t*-test on Segment 5 showed a nonsignificant reduction in the accident rate. The segment had 0.79 acc/mvm before restriping to add a lane, and 0.68 acc/mvm after restriping. Initially there were a full inside shoulder, four mainlanes, and a full outside shoulder. Restriping made a partial inside shoulder 3 ft wide and five narrower lanes; the full outside shoulder remained as before.

Samples were good in number but average to poor in observations per sample. The bar charts suggest that a bottleneck about milepoint 16.2 may have been cleared but there is no observable shift in accident pattern.

TABLE 2 OVERALL ACCIDENT RATES ON CALIFORNIA FREEWAYS WHERE INSIDE SHOULDERS WERE REMOVED

Seg. No.	Freeway, County Length, Direction	Period	Samples[1]	Mean (Acc/MVM)	T-Value	Probability of Greater T[2]
1.	I-5, Los Angeles	Before 7/15-6/78	12	1.066	1.08	0.29
	(1.34 mi., SB)	After 7/79-6/82	12	1.288		
2.	I-5, Los Angeles	Before 7/75-6/78	6	1.178	-1.65	0.13
	(0.69 mi., NB)	After 7/79-6/82	6	0.784		
3.	CA-22, Orange	Before 1/77-6/80	14	0.829	-2.33	0.03 *
	(3.25 mi., WB)	After 4/82-12/84	11	0.617		
4.	CA-60, Los Angeles	Before 1/79-6 81	5	0.905	-2.00	0.09
	(0.68 mi., EB)	After 1/83-12/84	4	0.683		
5.	CA-22, Orange	Before 1/77-6/80	12	0.789	-0.65	0.53
	(0.67 mi., NB)	After 10/82-12/84	9	0.685		
6.	I-405, Los Angeles	Before 1/74-3/75	5	0.793	-2.90	0.01 *
	(7.72 mi., NB)	After 4/77-12/79	11	1.058[3]		
7.	US-101, Marin	Before 1/80-6/82	5	0.649	-0.82	
	(0.31 mi., SB)	After 1/83-12/84	4	0.422		
8.	I-580, Alameda	Before 1/79-9/81	11	1.964	-2.33	0.03 *
	(0.61 mi., EB)	After 4/82-12/84	11	1.436[4]		
9.	I-680, Contra Costa	Before 1/80-12/81	4	1.066	-0.22	0.84
	(0.38 mi., SB)	After 7/82-12/83	3	1.015		
10.	CA-94, San Diego	Before 1/79-9/81	8	0.621	-0.69	0.50
	(1.13 mi., EB)	After 1/81-12/84	8	0.556		

[1]Each sample corresponds to the accident rate for a three month period.

[2]One asterisk (*) means statistically significant at the 0.05 level, and two asterisks (**) means statistically significant at the 0.01 level.

[3]See text for explanation of increase

[4]See text for description of project.

I-405, Los Angeles

Results of the *t*-test on Segment 6 indicated an increase in accident rates. This 8.58-mi segment experienced 0.79 acc/mvm before restriping and 1.06 acc/mvm after restriping. The after-restriping accident rate was significantly higher at the 0.05 level. Initially, this segment had a full inside shoulder, four mainlanes, and a full outside shoulder. After restriping, it had a partial inside shoulder 3 ft wide and five mainlanes; it retained the same full outside shoulder. Two short subsegments now have an auxiliary lane between on-to-off ramps in addition to the five mainlanes and full outside shoulder.

Samples before restriping were only five, and this number was less than desirable. Yet, observations were good, adding up to 1,185 and giving each sample a stable number. Examining the frequency bar charts provided a clue to these differences. There was a shift in accidents downstream (toward the north end) of this freeway segment. This shift was measurable by determining the percentage of all accidents that occurred in the last quarter of this segment before restriping, and comparing it

with the percentage of accidents occurring on the same subsegment after restriping. Before restriping, 16 percent of all accidents occurred along the last quarter-length (2.1 mi) of this segment; after restriping, 48 percent of all accidents occurred within that subsegment.

The good accident database allowed detailed lane analysis. Table 3 presents the results of *t*-tests performed for each lane. The inside and outside lanes experienced a nonsignificant reduction in accident rates after restriping. The inside and outside shoulders had too few accidents for this kind of analysis. On the other hand, middle lanes increased significantly in accident rates from 0.046 acc/mvm before restriping to 0.078 acc/mvm after restriping. This increase was very significant, at the 0.01 level. A histogram of accident frequency by lane at each 0.1 mi shows a high peak as traffic approaches the US-101 exit ramps.

Dividing the whole I-405 segment into three subsegments, each 2.9 mi long, allowed investigation of the shift observed in the histograms. An upstream, an intermediate, and a downstream subsegment each showed a different accident pattern. The upstream subsegment decreased very significantly from 1.22 to 0.84 acc/mvm. The intermediate subsegment increased nonsignificantly from 0.57 to 0.66 acc/mvm. The downstream subsegment almost tripled, from 0.60 to 1.68 acc/mvm. Table 4 presents these rates with more detail. It can be inferred that a safety problem was introduced in the third subsegment.

Data limitations preclude further partitioning of all lanes and subsegments. However, analysis was made of types of collisions in the middle lanes of the downstream subsegment. Rear-end collisions averaged 0.028 acc/mvm before improvements and 0.197 acc/mvm after. This sevenfold increase is statistically significant. Sideswipes increased but not significantly. Table 5 shows the midlane, rear-end accidents and rates of this downstream subsegment. Examination of the individual accident records also indicates an overrepresentation of afternoon peak-period accidents.

It can be inferred that taking the inside shoulder in the first two subsegments of I-405 was not detrimental to safety. This action improved accident rates in the first subsegment. The downstream subsegment experienced an increase in accident rates; however, the inside lane and shoulder had no influence in that change. Midlane weaving before the exit at the US-101 ramp, which had inadequate capacity, appeared to be the main reason behind the increase. This condition significantly increased midlane rear-end accidents on the downstream subsegment. The inside lane accident rate of this subsegment decreased. Therefore, the partial inside shoulder was not the cause of increased accidents.

The project was originally intended to be a HOV lane; however, it was implemented as a mixed-flow lane, resulting in a lane balance problem at its terminus.

US-101, Marin

Segment 7 results of the *t*-test indicated a nonsignificant decrease in accident rates. This segment had 0.65 acc/mvm before restriping and 0.42 acc/mvm after restriping. Restriping was accomplished to increase the number of mainlanes from three to four. The full inside shoulder was reduced to no inside

TABLE 3 I-405 *t*-TEST BY LANE, LOS ANGELES

Accident Location	Period	Sample[1]	Mean	T-Value	Probability of Greater T[2]
Inside Shoulder	Before		Unreliable data, too few observations		
	After				
Inside Lane	Before	5	0.067	-1.18	0.26
	After	11	0.054		
Middle Lanes	Before	5	0.046	4.34	0.01**
/Lane[3]	After	11	0.078		
Outside Lane	Before	5	0.129	-0.16	0.88
	After	11	0.126		
Outside Shoulder	Before		unreliable data, too few observations		
	After				

[1]Each sample corresponds to the accident rate for a three month period.

[2]One asterisk (*) means significant at the 0.05 level and two asterisks (**) means very significant at the 0.01 level.

[3]The number of inside lanes went from 2 before to 3 after, and the analysis is performed on a per lane basis.

TABLE 4 I-405 *t*-TEST BY SUBSEGMENT

Subsegment Location	Period	Samples[1]	Mean	T-Value	Probability of Greater T [2]
Upstream	Before	5	1.221	-4.23	0.001**
	After	11	0.835		
Intermediate	Before	5	0.573	0.93	0.37
	After	11	0.664		
Downstream	Before	5	0.598	5.90	0.0001**
	After	11	1.683		

[1]Each sample corresponds to the accident rate for a three month period.

[2]One asterisk (*) means significant at the 0.05 level and two asterisks (**) means very significant at the 0.01 level.

TABLE 5 I-405 MIDLANE REAR-END ACCIDENTS AT THE DOWNSTREAM SUBSEGMENT

Period	Year	Frequency (Acc/MVM)	Mean (Acc/MVM)
Before	74	0	
		(0)	
	75	1	
		(0.048)	(0.028)
After	77	6	
		(0.268)	
	78	4	
		(0.154)	
	79	4	
		(0.161)	(0.197)

shoulder and the outside shoulder was also reduced but remained a full outside shoulder 8 ft wide. This improvement was a solution to a local traffic problem created by trucks' entering the freeway from a truck weighing station while going uphill. This project is not typical of left-shoulder removal to increase capacity.

Accident observations for this short segment were very scant. Frequency bar charts were normal. Results would be insignificant standing alone; however, they are included for completeness of reporting on all sections that were provided for analysis.

I-580 Alameda

The *t*-test for Segment 8 indicated a decrease in accident rates significant at the 0.05 level. Before restriping, accident rates were 1.96 acc/mvm; after restriping, they were 1.44 acc/mvm. Before restriping, there were a full inside shoulder, four mainlanes, a 10-ft auxiliary lane with no outside shoulder, but a grass area to the right of the outside lane. After restriping, no inside shoulder was provided, four through lanes remained, the auxiliary lane was moved inside, and a 10-ft permissive lane (4:00–6:00 p.m.) was located where the auxiliary lane formerly was.

The sample number was good but the observations per sample were average to poor. The frequency bar chart indicates that a reduction around Milepost 43.0 ft may be related to weaving at the approach to the off-ramp. After restriping, the extra lane available for weaving during peak hours appeared to help reduce this problem.

I-680, Contra Costa

The *t*-test for Segment 9 indicated a nonsignificant reduction in accident rates. Before restriping, accident rates were 1.07 acc/mvm; after, they were 1.02 acc/mvm. Before restriping, a full inside shoulder existed with three through lanes and a full outside shoulder; after, no inside shoulder was provided, but three through lanes, an auxiliary lane between on-to-off ramps, and a full outside shoulder remained.

The number of samples and the number of observations per sample were limited. The frequency bar charts were not clear due to the scant number of observations although they appeared to indicate that accidents near Milepost 18.0 were reduced.

CA-94, San Diego

The *t*-test for Segment 10 indicated a nonsignificant reduction in the accident rate. Before restriping, the accident rate was 0.62 acc/mvm; after, it was 0.56 acc/mvm. Initially, there were a full inside shoulder, four mainlanes, and a full right shoulder. Restriping changed this to a partial inside shoulder 3 ft wide, five narrower lanes, and a full outside shoulder. A short segment had an auxiliary lane between on-to-off ramps.

The number of samples was adequate but the number of

observations per sample was poor. In spite of the limited observations, the frequency bar charts suggest a downstream shift in accidents. That is, the additional capacity relieved an upstream problem but recreated it at a reduced level further downstream.

ACCIDENT SEVERITY EXPERIENCE ON INSIDE SHOULDER REMOVALS

In addition to the general concern about traffic safety, a concern exists that the absence of a shoulder would increase accident severity even if the overall number of accidents decreased. The following analysis explores accident severity. This analysis is more difficult as the data are subdivided into more and more categories of fewer and fewer accidents. That is to say, no conclusions are appropriate if there was one accident before and two accidents after, because there is no statistical stability with a small number of observations. The severity analysis requires more aggregation of data than the overall analysis in order to make any inferences.

Table 6 presents the severity rates by study site for the 10 inside shoulder cases. An overall average was obtained dividing total accidents of each severity category by the combined number of vehicle-miles for all segments. The fatal accident rate was 0.0031 acc/mvm before and 0.0052 acc/mvm after. These rates were based on three fatal accidents before and seven fatal accidents after, but no conclusion was warranted because of the low number of accidents. The injury rate was 0.31 acc/mvm before and 0.32 acc/mvm after. If the injury and fatal accident rates are combined on a before-and-after basis, a paired *t*-test (unweighted) indicates that the differences are not statistically significant. However, a similar test for the non-

TABLE 6 ACCIDENT SEVERITY RATES ON CALIFORNIA FREEWAYS WHERE INSIDE SHOULDERS WERE REMOVED

Seg. No.	Freeway, County Length, Direction	Before Rate			After Rate		
		Fatal	Injury	Object	Fatal	Injury	Object
1.	I-5, Los Angeles (1.34 mi., SB)	0.000	0.46	0.60	0.020	0.53	0.73
2.	I-5, Los Angeles (0.69 mi., NB)	0.000	0.33	0.84	0.020	0.48	0.30
3.	CA-22, Orange (3.25 mi., WB)	0.003	0.26	0.56	0.006	0.25	0.36
4.	CA-60, Los Angeles (0.68 mi., EB)	0.000	0.26	0.64	0.000	0.47	0.22
5.	US-101, Los Angeles (0.67 mi., NB)	0.000	0.28	0.50	0.000	0.30	0.38
6.	I-405, Los Angeles[1]	0.000	0.29	0.93	0.000	0.30	0.53
	(7.72 mi., NB)	0.018	0.16	0.39	0.000	0.25	0.42
7.	US-101, Marin (0.31 mi., SB)	0.000	0.07	0.58	0.000	0.25	0.16
8.	I-580, Alameda (0.61 mi., EB)	0.000	0.97	0.99	0.000	0.82	0.61
9.	I-680, Contra Costa (0.38 mi., SB)	0.000	0.41	0.65	0.000	0.14	0.87
10.	CA-94, San Diego	0.000	0.27	0.35	0.023	0.28	0.25
	Weighted Average	0.003	0.31	0.61	0.005	0.32	0.44

[1]I-405 accident rates on the upstream and the intermediate subsegments only.

injury (property damage only) accidents indicates a decrease in noninjury accidents after the removal of left shoulders, statistically very significant at the 0.01 level. Therefore, there is no indication that accident severity is worsened by inside shoulder removal.

UPSTREAM AND DOWNSTREAM ANALYSIS

Besides analysis of the segments where inside shoulders have been reduced to provide a travel lane, sites upstream and downstream from segments undergoing a treatment were investigated. The term "site" is used here to refer to the segment upstream or downstream from the one that was restriped. Table 7 presents the accident experience of upstream and downstream sites. Only sites upstream and downstream from segments with a good accident database were considered, to allow for a meaningful correlation.

I-5, Los Angeles

Site 1, upstream from Segment 1, had a nonsignificant decrease in accident rates from 0.87 acc/mvm before restriping to 0.82 acc/mvm after restriping. Site 5, downstream from Segment 2, showed a nonsignificant decrease in accident rates, going from 0.72 acc/mvm before restriping to 0.52 acc/mvm after restriping. These results suggest that restriping and adding capacity had no effect on accident rates at adjacent sites.

CA-22, Orange

Site 3, upstream from Segment 3, was not considered because the site is located at the interchange with I-5 and other intervening factors affect traffic and its composition. Site 6, downstream from Segment 3, had a significant reduction in accident rates, from 0.73 acc/mvm before restriping to 0.48 acc/mvm after restriping. Reasons for the decrease were not apparent. The frequency bar charts reflect such decreases, but no unusual condition is evident.

I-405, Los Angeles

Both ends of this long segment were close to major interchanges. Therefore, the upstream and downstream sites were not considered for this analysis.

TABLE 7 ACCIDENT EXPERIENCE AT UPSTREAM AND DOWNSTREAM SITES[1]

Site No.	Freeway, County (Distance/Direction)	Period	Rate (Acc/MVM)	Comments
	Upstream from Segment No.[2]			
1.	1. I-5, Los Angeles (0.95 mi./SB)	Before	0.87	Decreased,
		After	0.82	not significant.
2.	8. I-580, Alameda (1.19/EB)	Before	1.52	Decreased,
		After	1.45	not significant.
3.	3. CA-22, Orange	Not considered; located at I-5 interchange.		
4.	6. I-405, Los Angeles	Not considered; located at I-10 interchange.		
	Downstream from Segment No.[2]			
5.	2. I-5, Los Angeles (0.96 mi./NB)	Before	0.72	Decreased,
		After	0.52	not significant.
6.	3. CA-22, Orange (1.23 mi./WB)	Before	0.73	Decreased,
		After	0.48	significant.
7.	6. I-405, Los Angeles	Not considered; located at US 101 interchange.		
8	8. I-580, Alameda	Not considered; had right shoulder work.		

[1]Only sites related to a segment with a good accident-sample base are included.

[2]Segment to which site is related; refer to Table 1.

I-580, Alameda

Site 2, upstream from Segment 8, experienced a nonsignificant reduction in accident rates that decreased from 1.52 acc/mvm before restriping to provide an extra lane to 1.45 acc/mvm after restriping. No unusual condition could be detected from the frequency bar charts. Site 8, downstream from Segment 8, included a subsegment where concurrently with the restriping project a right shoulder was removed and was not considered for analysis.

Based on analysis of the four upstream and the three downstream sites, it can be inferred that restriping of the segments studied had no negative effect on safety beyond the limits of the project.

EFFECTS OF CONGESTION

Table 8 summarizes the data in terms of the degree of congestion before and after the changes. The degree of congestion is shown in terms of ADT per lane. Only those sections with before ADT per lane greater than 20,000 showed accident reductions. Segments 3, 6, and 8, which experienced significant accident reductions, were most likely the result of some operational improvement. Segment 7, which did not have a reduction in accidents, is an atypical project. The I-680 Segment 8 database was poor. The accident reductions appeared to occur on the sections where ADT per lane was greater than 20,000 before the change and less than 18,000 per lane after the change. However, I-680, Contra Costa, had similar volumes but a nonsignificant reduction in the accident rate.

TABLE 8 RELATIONSHIP BETWEEN CONGESTION AND ACCIDENTS ON SECTIONS WITH INSIDE SHOULDER REMOVALS

Segment No. (Table 1)	Freeway, County	Congestion[1]		Significant Accident Reduction
		Before	After	
1	I-5 Los Angeles	14,400	13,300	No
2	I-5 Los Angeles	14,400	13,300	No
3	CA-22 Orange	20,600	16,900	Yes
4	CA-60 Los Angeles	15,200	11,200	No
5	US 101 Los Angeles	29,712	26,530	No
6	I-405 Los Angeles	20,900	20,100	Yes
7	US 101 Marin	16,300	13,300	No[1]
8	I-580 Alameda	20,200	16,700	Yes
9	I-680 Contra Costa	20,300	16,600	No[2]
10	CA-94 San Diego	11,300	10,700	No

[1]Congestion indicated as ADT per lane.

[2]This is a very atypical project.

[3]Poor database.

SUMMARY OF INSIDE SHOULDER EXPERIENCE

The experience with inside shoulder removals was either a nonsignificant change or a significant reduction in overall accidents at all freeway segments studied in California, with one exception. A significant increase at I-405 was determined to be related to a lane balance problem at the downstream terminus. In addition, total accidents in the first subsegment were reduced. Reduced accidents appear to be related to the lowered levels of congestion. The data suggest that accident reductions occur where the ADT/lane before is greater than 20,000 and the ADT/lane after is less than 18,000. The analysis also suggests that accident severity is not affected; the only significant change is a reduction in noninjury accidents.

ACKNOWLEDGMENTS

This study is the result of an informal cooperative arrangement supported by the Texas State Department of Highways and Public Transportation (SDHPT) and the California Department of Transportation (Caltrans). Funding was provided by the FHWA, U.S. Department of Transportation.

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Publication of this paper sponsored by Committee on Operational Effects of Geometrics.